Characterization of the Spatial Distributions and Optical Properties of Smoke Using Lidar Observations during SEAC4RS

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http://science.larc.nasa.gov/lidar

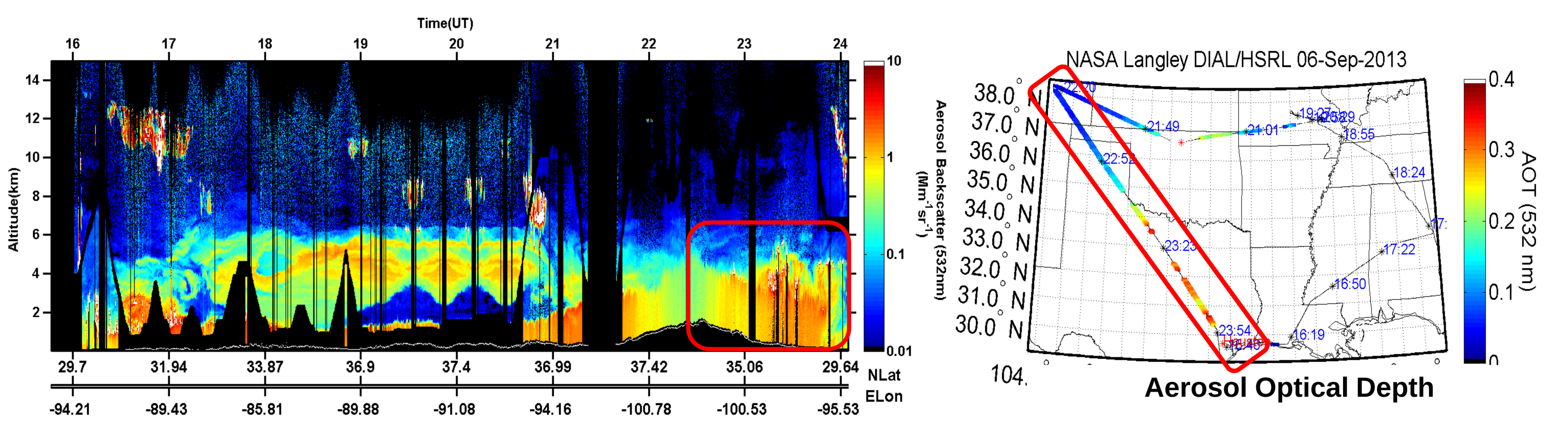
Introduction

The NASA Langley Research Center airborne combined Differential Absorption Lidar (DIAL) High Spectral Resolution Lidar (HSRL) characterized ozone and aerosol distributions while deployed on the NASA DC-8 during the Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) field campaign. In addition to measuring ozone concentrations throughout the troposphere and lower stratosphere, this advanced lidar system simultaneously measures aerosol extinction and aerosol optical thickness (AOT) at 532 nm via the HSRL technique, as well as aerosol backscatter and depolarization at 355, 532, and 1064 nm in both nadir and zenith directions.

The DIAL/HSRL measurements of lidar ratio (i.e., the ratio of extinction and backscatter), aerosol depolarization ratio, backscatter color ratio, and spectral depolarization ratio (i.e., the ratio of aerosol depolarization at the two wavelengths) provide information about the aerosol physical properties and so are combined to infer aerosol type. Aerosol extinction and optical thickness are apportioned to these aerosol types. Smoke from biomass burning is identified by the lidar data and the optical parameters along with the vertical and horizontal distributions are presented from the SEAC4RS campaigns. In addition, the DIAL/HSRL measurements from the research flight on August 6, 2013 are used to quantify and characterize smoke above uniform stratus clouds.

Example of DIAL/HSRL Data Products

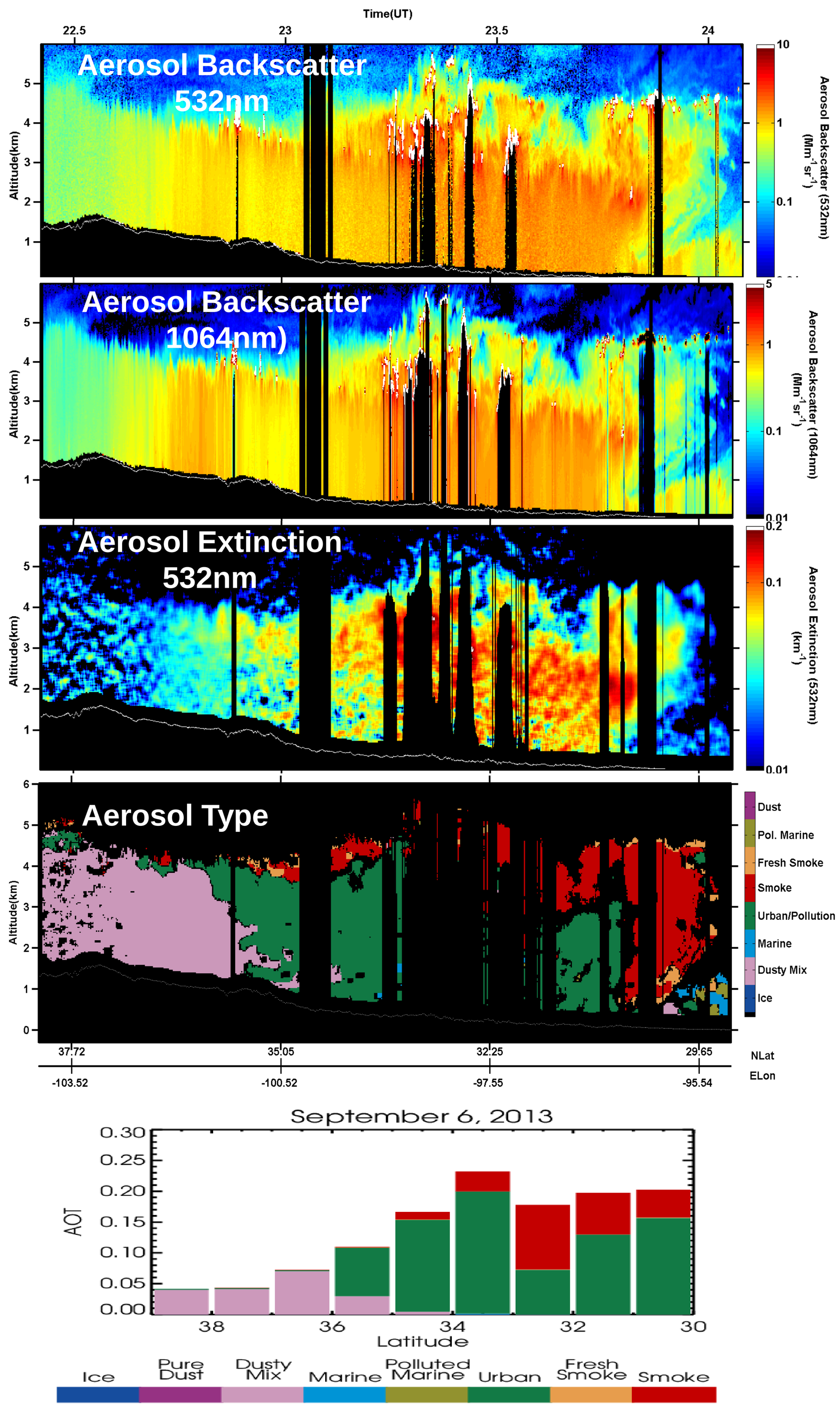
High Spectral Resolution Lidar (HSRL) Measurements



Parameters shown below are expanded views of flight segments outlined above

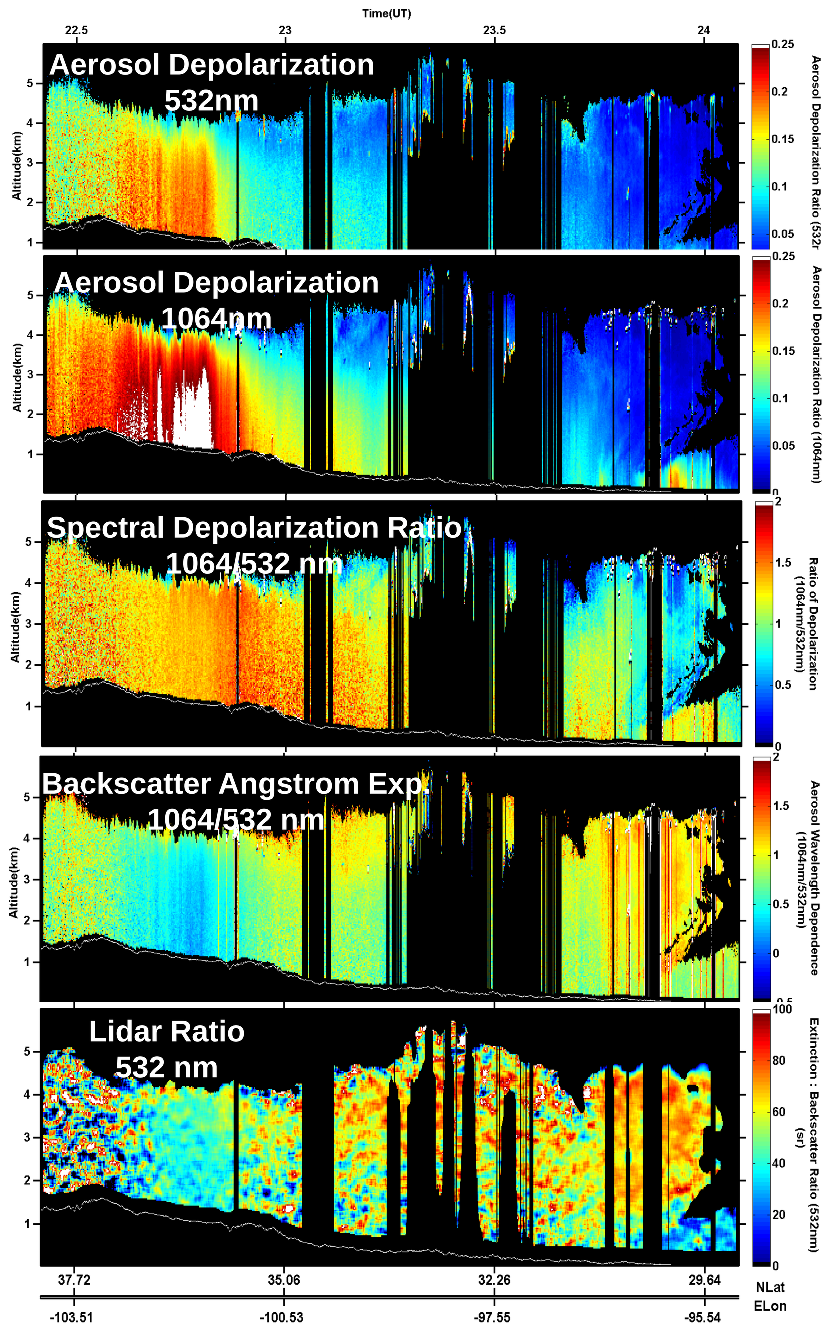
Extensive Parameters

(Depend on particle type and concentration)
Aerosol Backscatter (532nm)
Aerosol Backscatter (1064nm)
Aerosol Extinction (532nm)
Aerosol Optical Thickness (AOT – 532nm)



Intensive Parameters

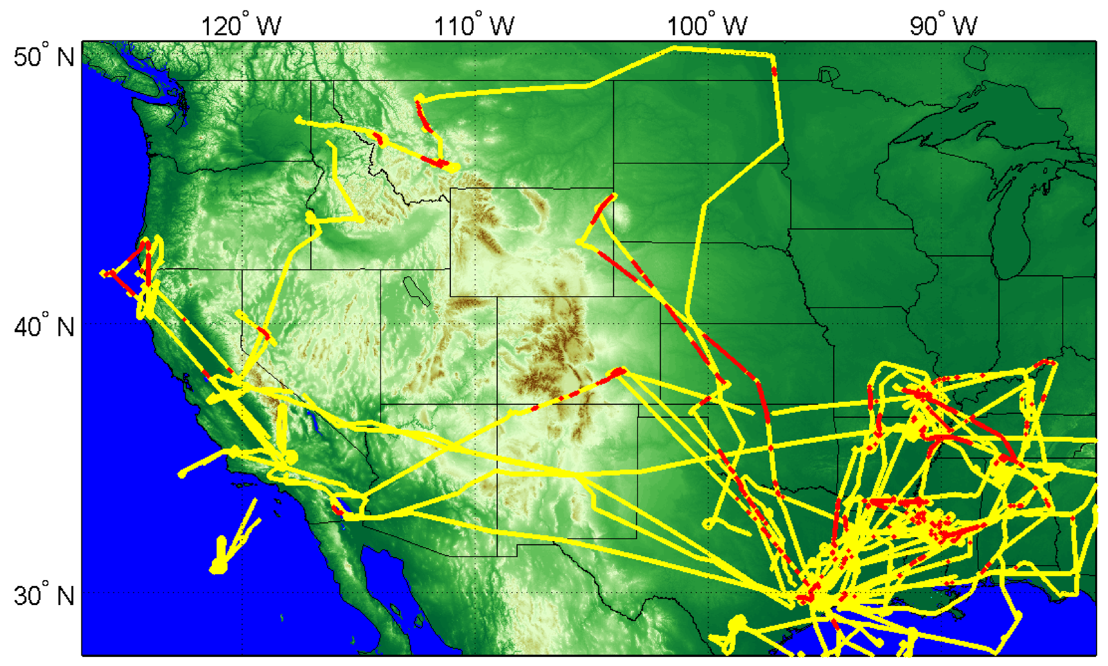
(Depend only on particle type - composition, size, shape)
Aerosol Depolarization (532nm)
Spectral Depolarization Ratio (1064/532nm)
Backscatter Angstrom Exponent (1064/532nm)
Lidar Ratio (Extinction-to-Backscatter Ratio 532nm)



Burton, S. P., et al. "Aerosol classification using airborne High Spectral Resolution Lidar measurements–methodology and examples." *Atmospheric Measurement Techniques* 5.1 (2012): 73-98.

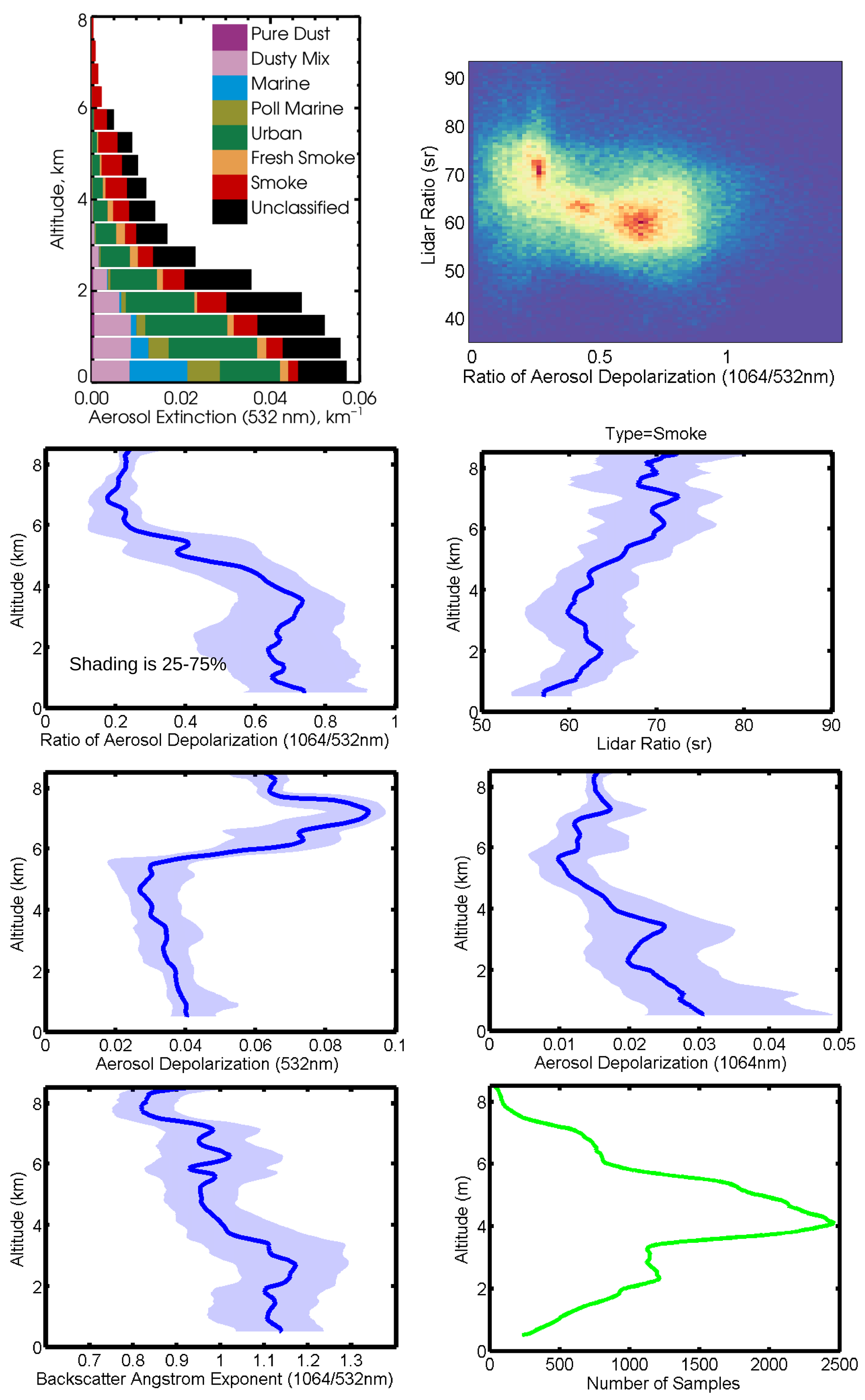
Aerosol Typing

The lidar intensive parameters (4) are used to infer aerosol type (coarse speciation) based on the methodology provided by Burton et al., 2012. Two of these types are smoke (likely more aged or processed) and fresh smoke. Although all of the intensive parameters are used in the typing analysis, two of them are key in the identification of smoke; the lidar ratio and depolarization, in particular the spectral dependence of the depolarization. Based on the aerosol typing as shown in the figure labeled Aerosol Type, the measured extinction can be integrated to provide the aerosol optical thickness (AOT) based on each type identified as shown in the bottom left panel along the flight. This example shows a case where dust dominated the northern latitude and more urban sources dominated the AOT at lower latitudes with smoke identified at higher altitudes.



DC8 flight tracks in yellow, red indicates segments where smoke was identified based on the lidar observations (AOT of smoke layer > 0.05)

Vertical Variability of Smoke Optical Properties



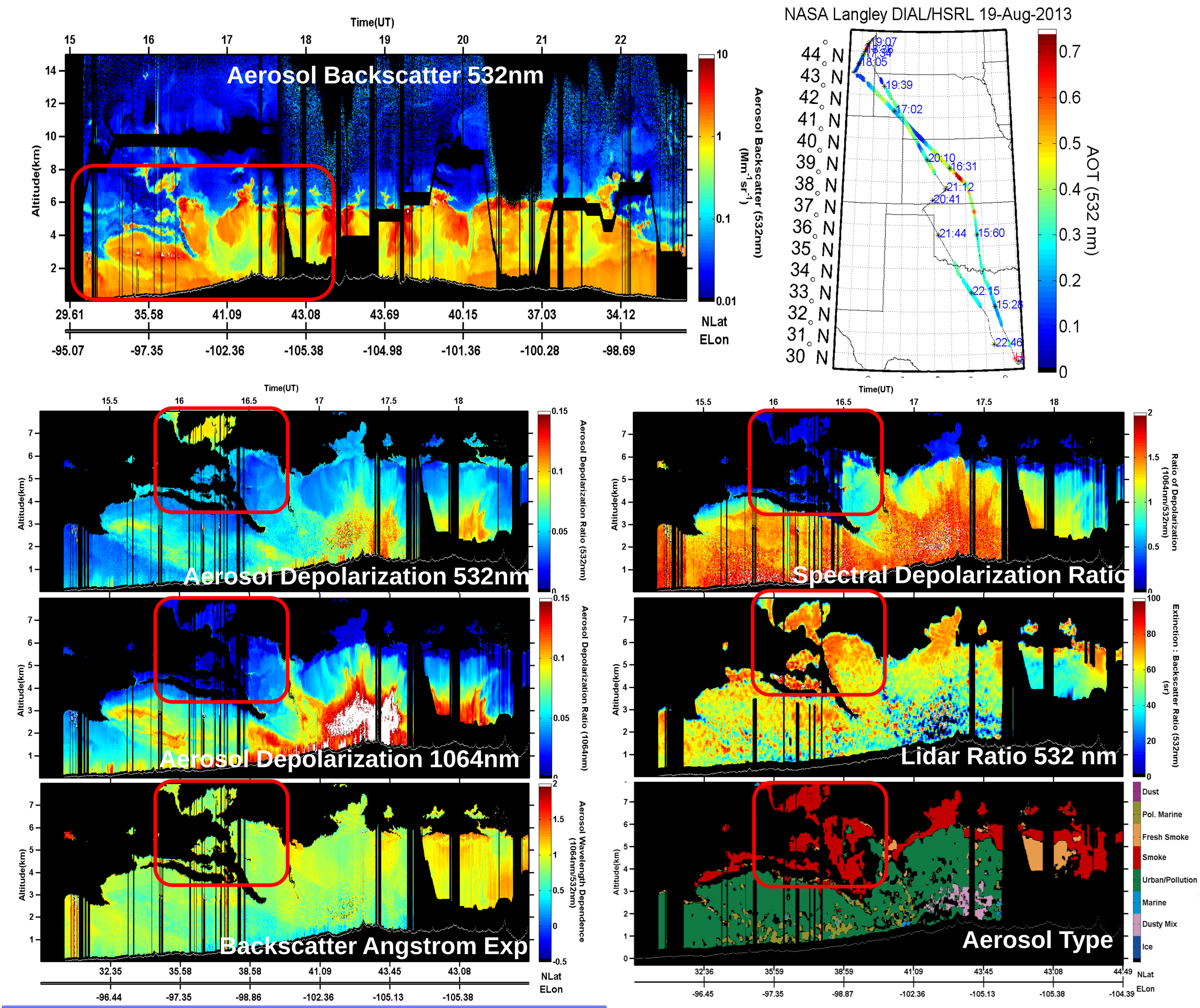
Comments on the Smoke Lidar Observations with Altitude

The HSRL technique allows independent measurements of the backscatter and extinction. In addition, using the methodology outlined by Burton et al., aerosol type can be inferred as a function of altitude and spatially along the flight tracks. Using these measurements and typing retrievals, the fraction of aerosol optical thickness (AOT) can be partitioned by type and altitude (see figure above). Compositing only aerosol types identified as smoke, the vertical variability was assessed for all the flights. As has been observed in previous individual flights, the averaged lidar ratio increases with altitude. This is correlated with an increase in the 532nm depolarization (the 1064nm does not show significant change) and therefore anticorrelated with the spectral depolarization ratio shown in the correlation plot.

Summary

- Smoke plumes were identified using the intensive parameters of the lidar observables during the SEAC4RS field mission. These are plotted to show the geographical distribution over the sampling region.
- The vertical distribution of aerosols was assessed based on the types identified
  - The aerosol optical thickness (AOT) was assessed as a function of aerosol types and altitude. The AOT was dominated by urban sources in the lower altitudes (<3km) and by smoke at higher altitudes (>4km).
  - For smoke types, the lidar ratio (extinction-to-backscatter) increased with altitude from a value near 60 below 5km to ~70 sr above. This increase is anticorrelated with the spectral depolarization indicating potential changes in the smoke microphysical parameters or mixing of aerosol types and relative humidity changes.
- The changes in the smoke properties with altitude can be important when deriving extinction from lidar systems that assign a lidar ratio in their retrievals (i.e. CALIOP) and it could be important in understanding the radiative effects of smoke in models.
- Observed changes in the spectral depolarization in various smoke plumes might provide more information about the smoke microphysics or aging. Further analyses using the depolarization and lidar ratio are required to assess the information content of the smoke particle microphysics (i.e. particle structure, number of primary particles).

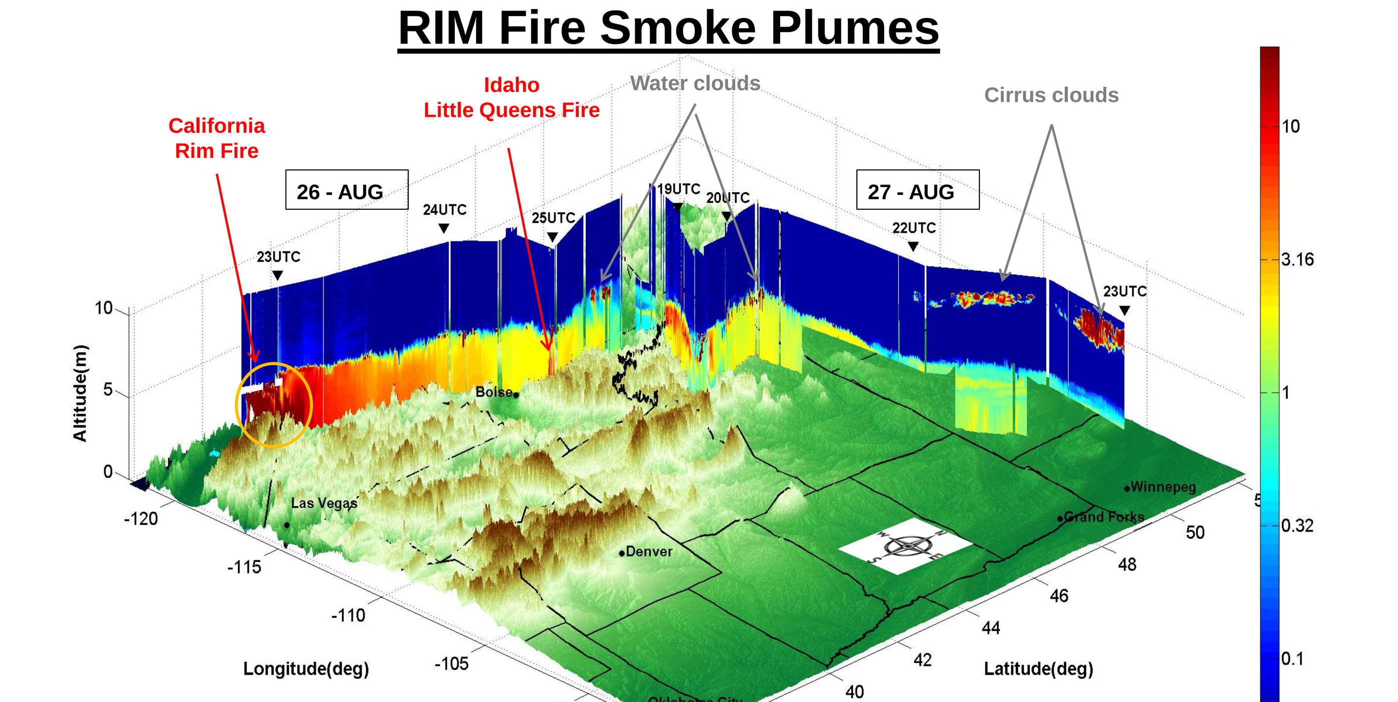
Case Study: Changes in Optical Properties



Example of Changes in Lidar Observations of with Altitude

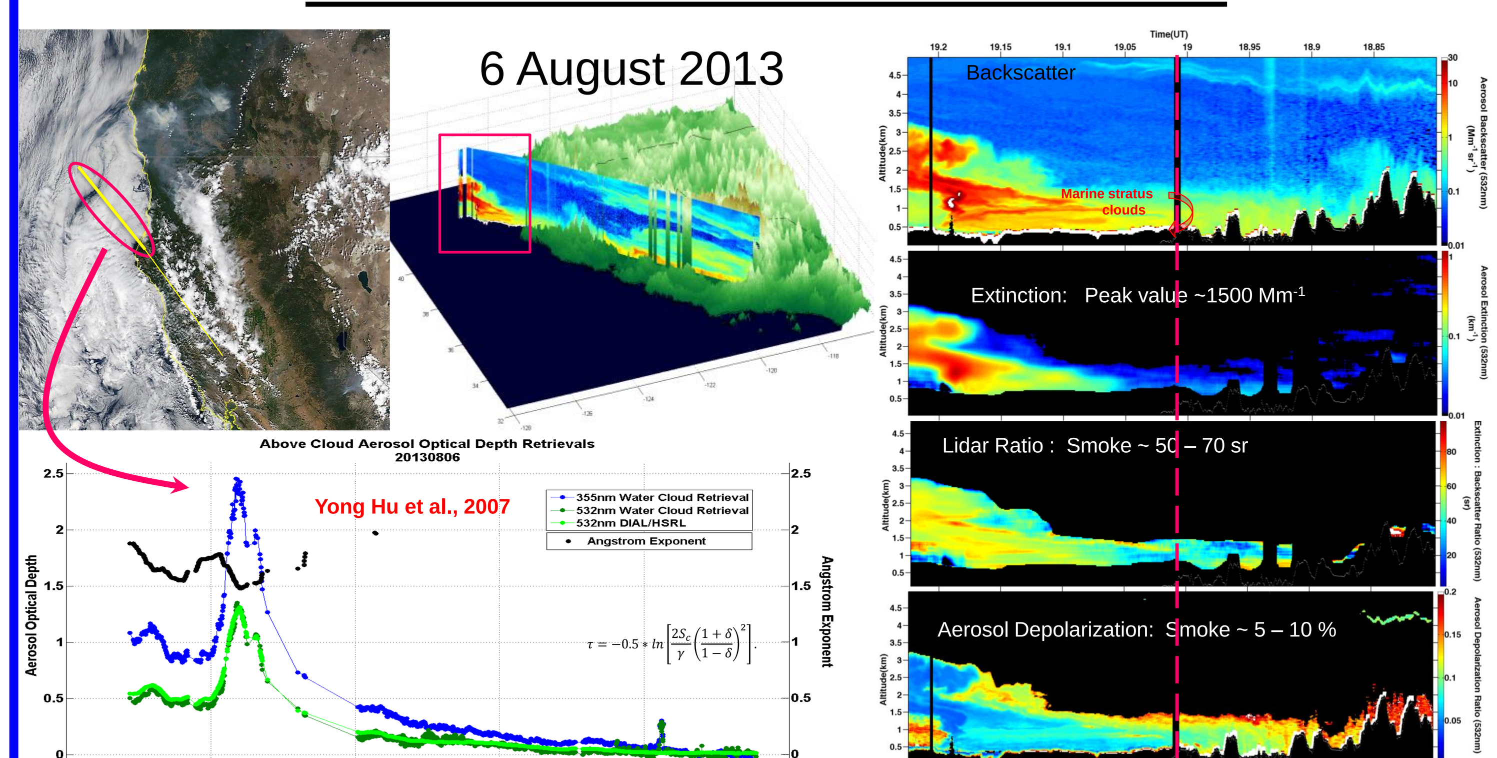
Note strong gradient in the spectral depolarization ratio near the top of the plumes encountered identified as smoke based on the lidar observations. In particular, there is very low depolarization at 1064nm in the identified smoke plume. In contrast, clear enhancements at 532nm are observed and in addition there are differences, ~2 and ~8% respectively, between the ~5&7km region at 16.25UT. This signature is not unique as previous measurements have also identified distinct differences in the smoke depolarization. The lidar ratio also increases with altitude. It is hypothesized that these differences offer information on the smoke microphysics (i.e. size, shape, or coating). However, it is noted that this change in optical properties could be due to mixing of different types or relative humidity changes.

RIM Fire Smoke Plumes



26-27 Aug. 2013: Curtain of aerosol backscatter along plume axis of RIM fire inside Yosemite National Park
See David Petersen et al., BAMS 2014

Above Cloud AOD Retrieval Assessment



Case study to assess accuracy of ACAOD retrievals from CALIOP

- Oregon/Washington smoke sampled off coast over stratus clouds. Provides case study to evaluate lidar retrievals.
- Using integrated attenuated backscatter (γ), the integrated depolarization (δ), and an estimated lidar ratio for the clouds S_c=19.3 based on previous estimates, the AOD optical depth can be retrieved over opaque clouds. (Yong Hu et al., 2007)
- Roughly 1/3 of CALIOP returns end in opaque clouds, allowing this retrieval method to be applied.
- Multiwavelength backscatter and depolarization measurements allow retrievals of AOD and Angstrom Exponents that can be assessed by other remote and in situ measurements during the smoke transect. Note the vertical changes in the optical intensive parameters.

Acknowledgements:

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